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INVESTIGATION OF THE TURBULENT FLOW OF MULTICOMPONENT FLUSHING --ETC(U)
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FOREIGN TECHNOLOGY DIVISION

INVESTIGATION OF THE TURBULENT FLOW OF MULTICOMPONENT FLUSHING FLUID BETWEEN TWO PARALLEL PLATES

by

R.M. Khasayev, A.K. Mamedov, A.T. Abbasov

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

Investigation of the Turbulent Flow of Multicomponent Flushing Fluid Between Two Parallel Plates

R. M. Khasayev, A. K. Mamedov, A. T. Abbasov

As investigations have shown in recent years [1], the structured flow of drilling flushing fluids and cement mortars is described by a viscoplastic model. However, in a turbulent motion mode, the structured viscosity and the critical shear stress becomes insufficient for the flow characteristics of multicomponent fluids.

According to [2], in a turbulent motion mode the effect of the viscous properties decreases, and the effect of the solid components in the fluid has a predominant influence on its motion. In accordance with the theory of the motion of fluids in a boundary layer the viscous properties are preserved near the walls and as the flow core is approached their effect disappears [3].

In connection with this, when calculating the turbulent flow of drilling flushing fluids, cement mortars and other multicomponent fluids it is advisable to break the fluid flow down into three areas:

1) into a a structured sublayer, where the motion is determined mainly by the viscous forces and by the forces of the critical shear stress;

2) into a turbulent transition layer, described by a Newtonian model with turbulent viscosity;

3) into a turbulently moving core, where the effect of viscosity is negligibly small.

On the basis of the accepted model the laws of the variation of friction stress can be represented accordingly for each area:

$$\tau_i = \begin{cases} \tau_0 = \tau_1 \dfrac{\partial v_1}{\partial y}; & i = 1; \quad 0 \leqslant y \leqslant \delta_1; \\ \tau_0 \dfrac{\partial v_2}{\partial y}; & i = 2; \quad \delta_1 \leqslant y \leqslant (\delta_1 + \delta_2); \\ \rho l^2 \left(\dfrac{\partial v_3}{\partial y}\right)^2; & i = 3; \quad (\delta_1 + \delta_2) \leqslant y \leqslant \dfrac{h}{2}. \end{cases}$$

In accordance with the accepted laws of variation in friction stress and in accordance with [1,3] let us take the velocity distributions in the individual areas of motion:

$$\left.\begin{array}{ll} v_1 = -\dfrac{\Delta p}{2l\tau_1} y^2 + c_1 y + c_2; & 0 \leqslant y \leqslant \delta_1; \\ v_2 = 8{,}57 v_* \left[\dfrac{v_*(y-\delta_1)}{\tau_0}\right]^{\frac{1}{7}} + c_3; & \delta_1 \leqslant y \leqslant (\delta_1 + \delta_2); \\ v_3 = 2{,}5 v_* \ln\left(\dfrac{y}{\delta_1 + \delta_2}\right) + c_4; & (\delta_1 + \delta_2) \leqslant y \leqslant \dfrac{h}{2}. \end{array}\right| \qquad (1)$$

As the boundary conditions for the determination of the unknown constants of integration let us take

$$
\begin{aligned}
&v_1(0) = 0; \quad v_1(\delta_s) = v_2(\delta_s);\\
&v_2(\delta_s + \delta_t) = v_3(\delta_s + \delta_t);\\
&v_3\left(\frac{h}{2}\right) = v_{\text{макс}};\\
&\tau_0 = \eta \frac{\partial v_1}{\partial y}\Big|_{y=\delta_s} = \frac{\Delta p(h-2\delta_s)}{2l};\\
&\tau_0 = \eta_1 \frac{\partial v_1}{\partial y}\Big|_{y=\delta_s} + \tau_{1T} \frac{\partial v_2}{\partial y}\Big|_{y=\delta_s+\delta_T} = \frac{\Delta p \delta_T}{l};\\
&\rho l^2 \left(\frac{\partial v}{\partial y}\right)^2\Big|_{y=\delta_s+\delta_T} = \frac{\Delta p[h-2(\delta_s+\delta_T)}{2l}.
\end{aligned}
\tag{2}
$$

where v_1, τ_1; $v_2\tau_2$; $v_3\tau_3$ are the averaged velocities and friction stresses respectively in each area; h is the distance between the plates; δ_s, δ_T are the thicknesses of the structured boundary layer and the turbulent sublayer; η_1, η_T are the structured and turbulent viscosity of the fluid; τ_0 is the critical shear stress; v_*, v'_* are the dynamic velocity respectively for the transition turbulent sublayer and the turbulent core; ρ is the density of the fluid; l is the value which expresses the approximate law of the fractionation of the law (sic) [Translator's note: probably should be - flow] into layers with similar distributions of relative averaged velocities.

Employing the conditions of (2) from equation (1) let us compile the following equations:

$$
\left.
\begin{aligned}
&-\frac{\Delta p}{2l\eta_1} 0 + c_1 0 + c_2 = 0;\\
&-\frac{\Delta p}{2l\eta_1}\delta_s^2 + c_1\delta_s = c_3;\\
&8{,}57v_* \left[\frac{\rho v_* \delta_T}{\eta_T}\right]^{\frac{1}{7}} + c_3 = c_4;\\
&v_{\text{макс}} = 2{,}5v'_* \ln\frac{h}{2(\delta_s+\delta_T)} + c_4;\\
&\tau_0 = \eta\frac{\Delta p}{l\eta}\delta_s - \eta c_1 = \frac{\Delta p(h-\delta_s)}{2l}
\end{aligned}
\right\}
\tag{3}
$$

From joint solution (3) we will have:

$$\left.\begin{aligned}
&c_1 = \frac{\tau_0}{\tau_i} - \frac{\Delta p \delta_n}{l\tau_i} - \frac{\Delta p(h-\delta_n)}{2l\tau_i}; \quad c_2 = 0;\\
&c_3 = \frac{\tau_0\delta_n}{\tau_i} - \frac{\Delta p\delta_n^2}{l\tau_i} - \frac{\Delta ph\delta_n}{2l\tau_i};\\
&c_4 = 8{,}57 v_* \left[\frac{\rho v_* \delta_\tau}{\eta_\tau}\right]^{\frac{1}{7}} + \frac{\tau_0\delta_n}{\tau_i} - \frac{\Delta p\delta_n^2}{l\tau_i} - \frac{\Delta ph\delta_n}{2l\tau_i};\\
&v_{\max} = 8{,}57 v_* \left[\frac{\rho v_* \delta_\tau}{\eta_\tau}\right]^{\frac{1}{7}} + 2{,}5 v_* \ln \frac{h}{2(\delta_n+\delta_\tau)} +\\
&+ \frac{\tau_0\delta_n}{\tau_i} - \frac{\Delta p\delta_n^2}{l\tau_i} - \frac{\Delta ph\delta_n}{2l\tau_i}.
\end{aligned}\right\} \qquad (4)$$

Having substituted the values c_1, c_2, c_3, c_4 and $v_{\max}$ from (4) in (2) we will have:

$$\left.\begin{aligned}
&v_1 = -\frac{\Delta p y^2}{2l\tau_i} + \left(\frac{\tau_0}{\tau_i} - \frac{\Delta p\delta}{2l\tau_i} - \frac{\Delta ph}{2l\tau_i}\right) y;\\
&v_2 = 8{,}57 v_* \left[\frac{\rho v_* (y-\delta_n)}{\eta_\tau}\right]^{\frac{1}{7}} + \frac{\tau_0\delta_n}{\tau_i} - \frac{\Delta p\delta_n^2}{l\tau_i} - \frac{\Delta ph\delta_n}{2l\tau_i};\\
&v_3 = 2{,}5 v_* \ln\left(\frac{y}{\delta_n+\delta_\tau}\right) + 8{,}57 v_* \left[\frac{\rho v_* \delta_\tau}{\eta_\tau}\right]^{\frac{1}{7}} + \frac{\tau_0\delta_n}{\tau_i} - \frac{\Delta p\delta_n^2}{l\tau_i} - \frac{\Delta ph\delta_n}{2l\tau_i}.
\end{aligned}\right\} \qquad (5)$$

Let us determine th flow rate of the multicomponent fluid between the two parallel plates

$$Q = 2\int_0^{\delta_n} v_1 dy + 2\int_{\delta_n}^{\delta_n+\delta_\tau} v_2 dy + 2\int_{\delta_n+\delta_\tau}^{\frac{h}{2}} v_3 dy \qquad (6)$$

Substituting the values v_1, v_2 and v_3 from (5) in (6), we will have:

$$\begin{aligned}
Q = &-\frac{\Delta p}{2l\tau_i}\int_0^{\delta_n} y^2 dy + \left(\frac{\tau_0}{\tau_i} - \frac{\Delta p\delta_n}{2l\tau_i} - \frac{\Delta ph}{2l\tau_i}\right)\int_0^{\delta_n} y dy +\\
&+ 8{,}57\left[\frac{\rho v_*}{\eta_\tau}\right]\int_{\delta_\tau}^{\delta_n+\delta_\tau} (y-\delta_n) dy + \left(\frac{\tau_0\delta_n}{\tau_i} - \frac{\Delta p\delta_n^2}{l\tau_i} - \frac{\Delta ph\delta_n}{2l\tau_i}\right)\int_{\delta_n}^{\delta_n+\delta_\tau} dy +\\
&+ 2{,}5 v_* \int_{\delta_n+\delta_\tau}^{\frac{h}{2}} \ln\frac{y}{\delta_n+\delta_\tau} dy + \left[8{,}57 v_* \left(\frac{\rho\delta_* \delta_\tau}{\eta_\tau}\right)^{\frac{1}{7}} + \frac{\tau_0\delta_n}{\tau_i} - \frac{\Delta p\delta_n^2}{l\tau_i} - \frac{\Delta ph\delta_n}{2l\tau_i}\right]\int_{\delta_n+\delta_\tau}^{\frac{h}{2}} dy.
\end{aligned}$$

After carrying out integration and the appropriate transformations for the flow rate of the fluid we will obtain the expression:

$$Q = \frac{(3\tau_0 l - \Delta p h - 6\Delta p\delta_n)\delta_n^2 + (6\tau_0 l - 3\Delta p h)\delta_n\delta_\tau - 4\Delta p\delta_n^2}{3l\eta} + \\ + 5v_*'\left[\frac{h}{2}\left(\ln\frac{|h}{2(\delta_n+\delta_\tau)} - 1\right) + \delta_n + \delta_\tau\right] + 15v_*\delta_\tau\sqrt[7]{\frac{\rho v_*\delta_\tau}{\eta_\tau}} + \\ + \left(8{,}57v_*\sqrt[7]{\frac{\rho v_*\delta_\tau}{\eta_\tau}} + \frac{2\tau_0 l\delta_n - 2\Delta p\delta_n^2 - \Delta p h\delta_n}{2l\eta_\tau}\right)|h - 2(\delta_n+\delta_\tau)| \qquad (7)$$

In equation (7) δ_n and δ_τ, are also unknowns, which can be determined from the following equations, compiled in accordance with the conditions of (2):

$$\delta_n = h - \frac{2{,}45l\eta_\tau v_*}{\Delta p}\cdot\left(\frac{\rho v_*}{\eta_\tau}\right)^{\frac{1}{7}}\delta_\tau^{-\frac{6}{7}} + 2\delta_\tau;$$

$$\delta_n + \delta_\tau = \frac{h}{6} + \left\{\frac{h^3}{216} - \frac{3{,}06\rho l^3(v_*')^2}{\Delta p} + \left[\left(\frac{h^3}{216} - \frac{3{,}06\rho l^3(v_*')^2}{\Delta p}\right)^2 - \right.\right. \\ \left.\left. - \frac{125h^6}{105{,}97}\right]^{\frac{1}{2}}\right\}^{\frac{1}{3}} + \left\{\frac{h^3}{216} - \frac{3{,}09\rho l^3(v_*')^2}{\Delta p} + \left[\left(\frac{h^3}{216} - \right.\right.\right. \\ \left.\left.\left. - \frac{3{,}06\rho l^3(v_*')^2}{\Delta p}\right)^2 - \frac{125h^6}{105.97}\right]^{\frac{1}{2}}\right\}^{\frac{1}{3}}, \qquad (8)$$

where

$$v_* = \left[\frac{2l\tau_0(\eta-1) + \Delta p(3\delta_n + h)}{2\rho l\eta_\tau}\right]^{\frac{1}{2}};$$

$$v_*' = \left\{\frac{[2l\tau_0(\eta-1) + \Delta p(3\delta_n + h)](\delta_n+\delta_\tau)^2}{12{,}5\rho l^3\eta}\right\}^{\frac{1}{2}}.$$

Equations (7) and (8) make it possible in the determination of the flow rate of the multicomponent fluid during its turbulent motion to take into acount the effect of the viscoplastic properties of the fluids (η, τ_0) and the concentration of the solid particles (η_τ) in it.

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